Advanced Thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries

PPG, OI, Alcoa, Leadbetter, MTU & PNNL

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Project Summary

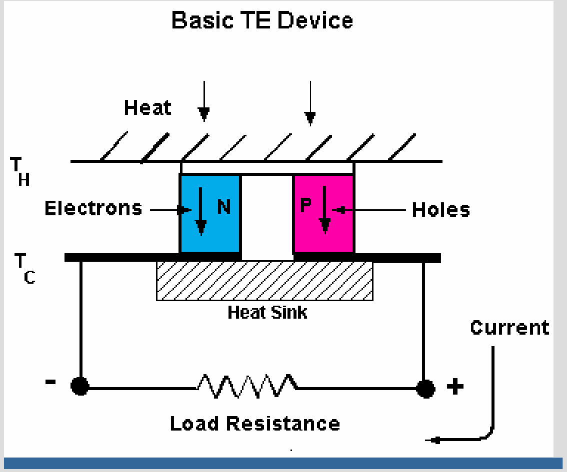
Goal: Integrate advanced thermoelectric materials into thermoelectric power generation device with efficiency >20% for waste heat recovery in industrial processes.

Challenge: Multi-layered, thin-film materials show promise for thermoelectric performance but economical scalability is required

Benefits: Recovery of energy from industrial waste heat stacks; conversion of waste heat into electrical power; energy savings of 1.6 trillion Btu/year in 2020.

FY05 Activities: Evaluate new materials and multilayer concepts; incorporate materials into prototype power generating device; fabricate and demonstrate 1 kW device.

Hot side ("Waste Heat")



Cold side

Barrier-Pathway Approach

Barriers

- Low energy efficiency furnaces due to heat loss
- Need for large scale production of high efficiency TE materials

Pathways

- Development of thin film thermoelectric materials
- Design of retrofit TE generators for implementation in waste heat stacks
- Cost / location trade-off studies for deployment of TE technology

Critical Metrics

- TE Figure of merit ZT > 3
- Electrical power produced from waste heat at a cost < 1 ¢ / kW-hr
- By 2020:
  - Energy Savings of 135 Trillion Btu
  - Cost Savings for of $ 980 Million
  - Carbon reduction of 0.4 MMTCe

Team Members

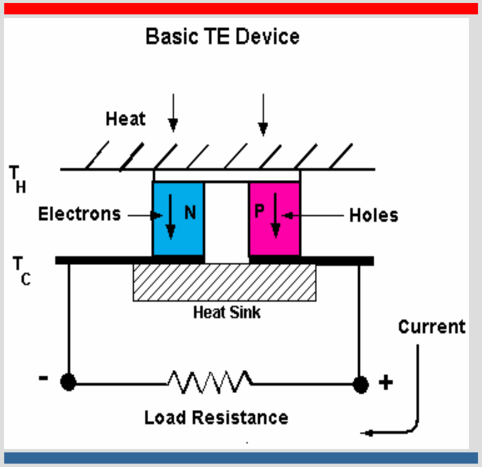
- **PPG Industries**
  - TEG in-situ device testing
  - Emission measurements
  - Combustion optimization
  - Process integration
  - Trade-off studies
- **PNNL**
  - TE materials development
  - Heat flow modeling
  - TEG device development and testing
  - Trade-off studies
- **Alcoa**
  - TEG in-situ device testing
  - Process integration
  - Trade-off studies
- **Owen-Illinois**
  - TEG in-situ device testing
  - Process integration
- **A. C. Leadbetter & Sons, Inc.**
  - TE materials development
  - Heat flow modeling
  - TEG device development and testing
- **Michigan Technological University**
  - Heat flow modeling
  - TEG device development

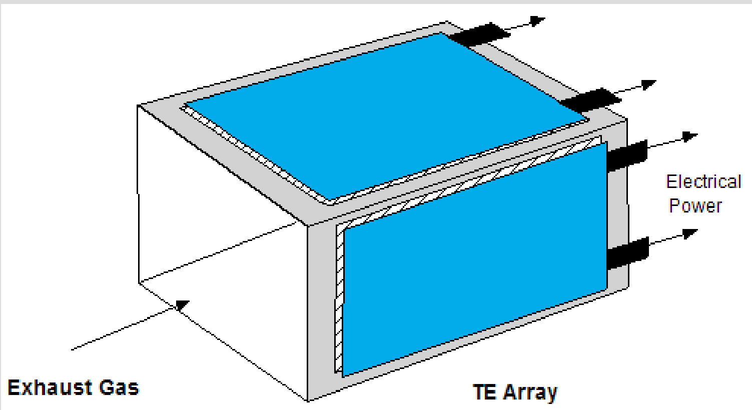
Thermoelectric Generators for Waste Heat Recovery

- <u>Large Quantities of Thermal</u> Energy are Available From Waste Energy Streams

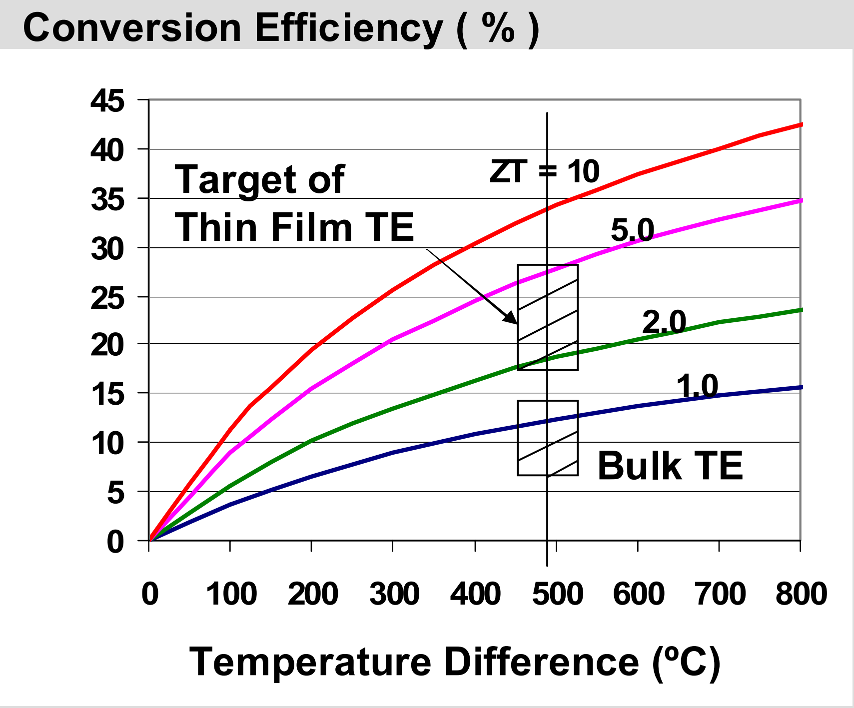
- Generation of Electrical Power with Therrmoelectrics Will Involve <u>Placing TE Arrays on the Sides</u> of Waste Energy Ducts

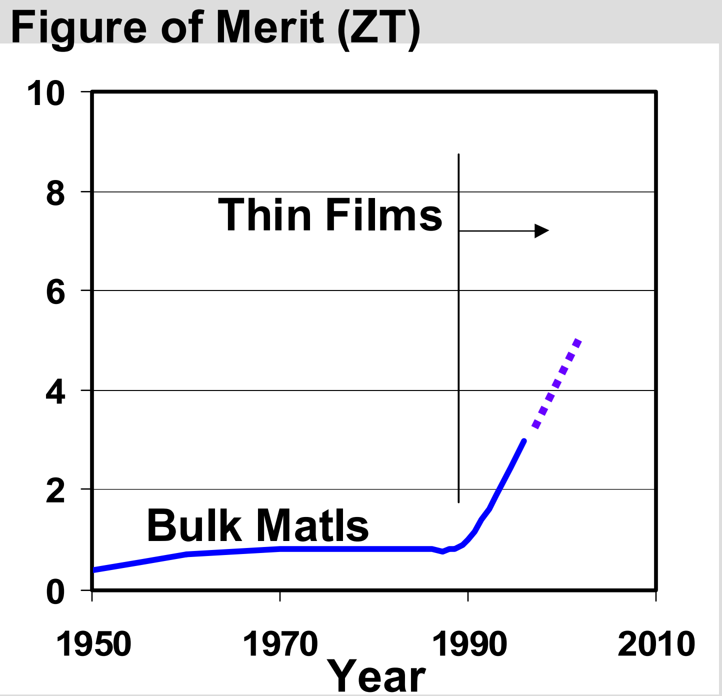
- <u>Key TE Material Challenges</u>:
  - Increase TE Efficiency
  - Scale-Up Fabrication Process to Reduce Cost





Potential of Thin Films





TEG System Components

- Heat Exchanger Coupled to Waste Heat Source
- TEG Module
- Cold Side Heat Exchanger

TEG System Design

Heat source selection
MTU, PPG, Alcoa, OI

→

Heat flow modeling
PNNL

→

Performance requirements
All

→

HX/TEG design
Leadbetter,
PNNL

→

TE materials
HX fabrication
Leadbetter,PNNL

→

TEG test module
PPG, Alcoa, OI,
PNNL

Program Plan

Tasks	FY04	FY05	FY06	FY07
1. Design Energy Conversion System		Current PNNL Matls; Economic Analysis		Advanced Materials; Update Economic Analysis
2. Advanced Large Scale TE Materials Development		ZT > 3; Scale-Up; Advanced Matls	ZT > 4	Scale-Up; ZT > 5
3. TE Generator Fabrication & Testing		10 % Demonstration: Bench Test at PNNL & with Slip Stream At PPG		20% Demonstration
4. Combustion Emission Optimization		Analyses of Particulate Deposition And Effect on Heat Transfer		

Task Descriptions

Task 1 - Design of Energy Conversion System

- Heat transfer analysis at hot and cold surfaces
- Electrical power characteristics of TE arrays

Task 2 - Advanced Large Scale TE Materials Development

- Optimize process for current PNNL materials to achieve ZT >3
- Investigate advanced materials to achieve larger values of ZT
- Develop approaches to for scale-up of deposition processes

Task 3 - TE Generator Fabrication & Testing

- Work with Industrial partners to design systems for bench top testing at PNNL and testing at industry sites

Task 4 - Combustion Emission Optimization

- Interact with Industrial partners to determine particulate deposition
- Model effects of particulates on heat transfer characteristics

Progress for FY04

- Kick-Off Meeting held at PPG with representatives from all Industrial partners

- Interaction with industries initiated to define best locations for placement of a TE array, acquire information concerning exhaust gas composition and particulate densities

- Heat transfer modeling for system design initiated

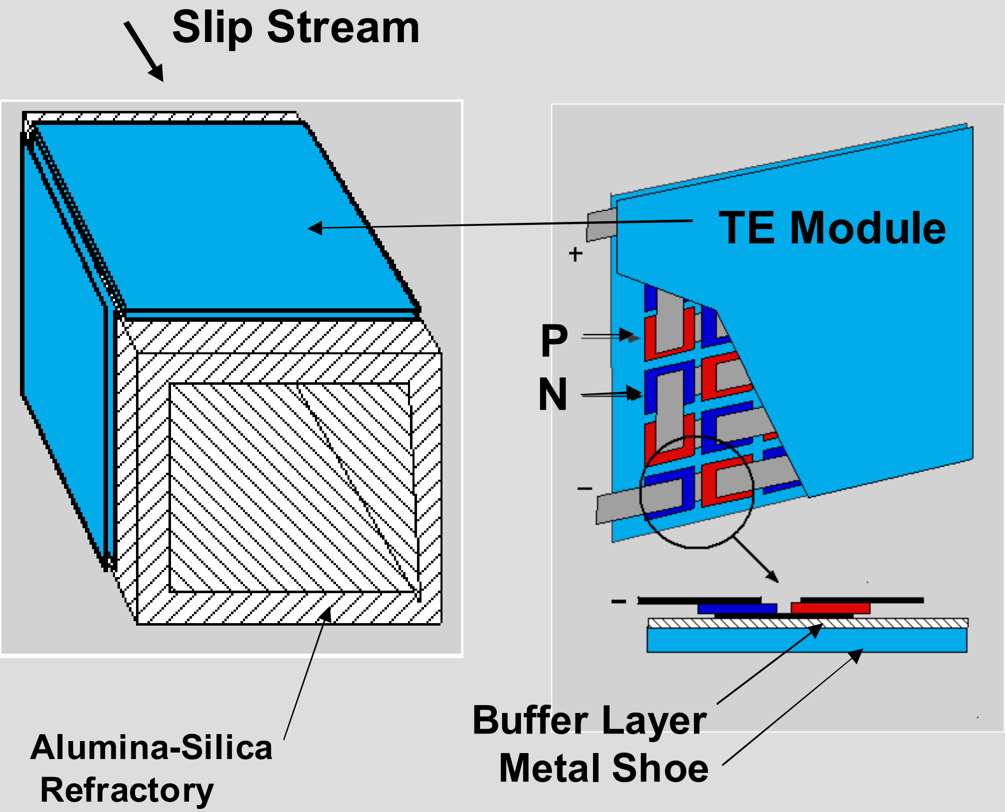
- Thin film thermoelectric materials development concentrating on;
  - Si/SiGe Multilayer films
  - Boron-Carbide Films
  - Contact technology and TE array design

Planned Activity for FY05

- Optimize Process for Current PNNL Materials with ZT > 3
- Develop Scale-up Process for Current PNNL Materials
- Initiate development of Advanced TE Materials
- Fabricate Thermoelectric System for Bench Top Testing and Testing at Industrial Partners
- Produce Electrical Power from a Waste Stream with a 10 % Efficiency

Preliminary Concept for Waste Heat Conversion Test Bed

- Assumptions:
  - Utilize Slip Stream from Oxy-Furnace-Gas at 2700°F
  - Temperature at Hot Shoe 1160ºF (900°K) with 1 cm Firebrick
  - Using Water Cooling Cold Shoe at 73°F (300°K)
- Heat Flow into TE Modules: 1.3 W/cm^2
- Four 1 meter x 10 cm TE Converters:
  520 Watts @ 10% Efficiency
  1040 Watts @ 20% Efficiency



Projected Cost Of Electrical Power From Waste Recovery

Case 1

Assumptions:
- Preliminary Concept with 1.3 W/cm^2
- TE Module Cost = \$ 1000/m^2
- five Year Continuous Operation
- TE Conversion Efficiency = 20%

Estimated Cost of Electricity = 1 ¢/kW-Hr

Case 2

Assumptions:
- Modification of Preliminary Concept to Give 10 W/cm^2
- TE Module Cost = \$ 1000/m^2
- One Year Continuous Operation
- TE Conversion Efficiency = 20%

Estimated Cost of Electricity $\leq$ 1 ¢/kW-Hr

Commercialization Pathway

- ❑ Development of Advanced TE Materials Which Convert Waste Heat to Electrical Power with an Efficiency of 20 %
- ❑ Demonstration of System at PPG and Other Industrial Partners That Produces 20 kW/m2 with an Efficiency of 20 %
- ❑ Establish Pilot Production Line at One or More of Industrial Partners for TE Module and System Fabrication

❑ As a Follow on Activity PNNL will Work with PPG Coating Groups to Develop in House Large Scale Coating Technology for TE fabrication.

❑Simultaneous Work with Battelle to Commercialize Technology.

CONCLUSIONS

- Research and Development Team Includes TE Materials Developers and Process Industries

- Design Studies for TE System for Bench Top Testing and Testing at Industries are Underway

- Development of Efficient Thin Film TE Materials Based on Si/SiGe and Boron Carbide Multilayers is Expected to Lead ZT Values > 3 -- Possible Efficiencies of 15% to 20%

- Three Year Program Should Provide Technology for Generating Power from Waste Heat with an Efficiency > 20 % and Electrical Power at a Rate < 1 ¢ / kW-Hr